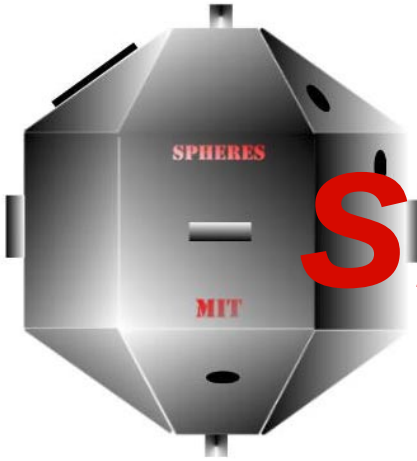


SPHERES

Synchronized Position Hold, Engage, Reorient, Experimental Satellites

Overview

April 2002

Steve Sell

Payload Systems Inc.

sell@payload.com

Introduction

What is SPHERES?

SPHERES…

- Is an ISS internal testbed for the development and testing of formation flying and other multi-spacecraft control algorithms
- Consists of three self-contained eight-inch diameter free-floating satellites which perform the various algorithms
- Uses data collected from one test session to build the algorithms for the next test session
- Is an interactive testbed -- ISS crew members command & observe the programmed maneuvers

SPHERES Team

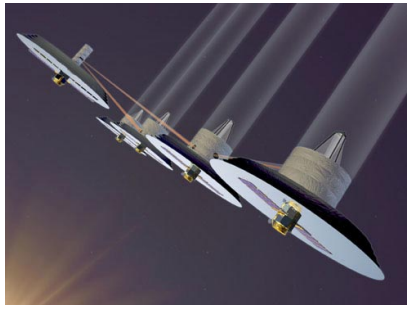
Who's involved:

- DARPA Orbital Express Program
  - Research and flight opportunity sponsor
- Massachusetts Institute of Technology
  - Principal Investigator: Prof. David Miller
  - Prototype design and testing
  - Algorithm development
- Payload Systems Inc.
  - Flight hardware design, fabrication & testing
  - Flight hardware integration & safety
- DoD Space Test Program and ISS Payload Integration Office
  - Flight manifest on ISS
  - Payload integration & safety support

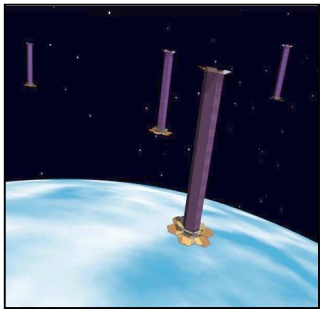
Science Motivation

- To reduce cost and improve performance, many missions are considering distributed spacecraft architectures
- Routine and autonomous formation flight is essential to the operation of these missions
- Long duration μ-*g* is impossible to simulate in the laboratory
- Therefore, an on-orbit testbed is needed to conduct research in μ-*g* for maturing these technologies

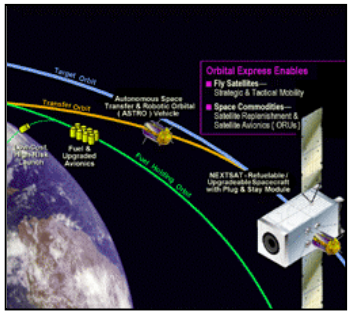
StarLight



Terrestrial Planet Finder



TechSat 21



Orbital Express

Science Objective

- SPHERES will serve to mature autonomous satellite formation flight, rendezvous and docking algorithms in a long duration, micro-gravity environment.
  - Allow for the interchange of control algorithms, the acquisition and analysis of data, and a truth measure
  - Demonstrate key close proximity formation flight and docking maneuvers
  - Demonstrate autonomous fault diagnosis and recovery
  - Ensure the adaptability of control algorithms to future formation flight missions

Why fly inside ISS?

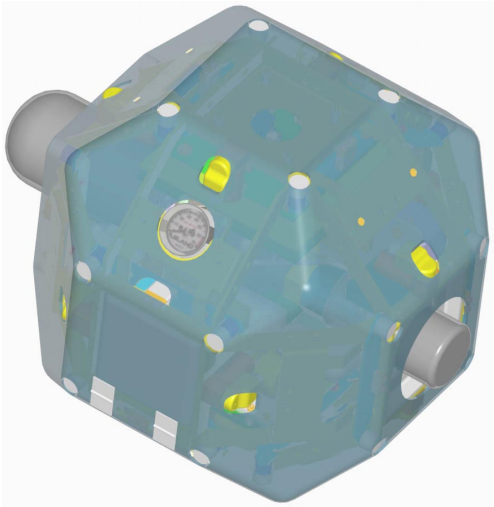
- Testing in the internal volume of ISS permits rapid algorithm iteration and dramatically reduces mission risk
  - Failed algorithm does not result in the loss of the payload
  - More likely to pursue ambitious test objectives
- ISS provides the benefits of a research laboratory-like setting, but in the microgravity environment
  - Human-in-the-loop research will allow testing to be guided along more productive routes
  - Consumables can be replenished
  - Video and crew commentary will provide valuable feedback to research team
  - Through iterative algorithm development, use last week's results to develop this week's tests

Mission

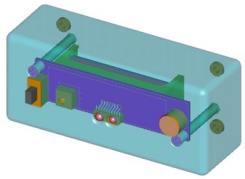
- SPHERES on ISS for two crew rotations
  - Ascent flight ISS-12A.1 (STS-116) May 2003
  - Re-supply flight ISS-13A.1 (STS-118) for replacement of consumables
  - Descent flight ISS-15A (STS-119) January 2004
- Operation time
  - Allocated 24 hours operation time (twelve 2-hour sessions with option for eight 3-hour or six 4-hour sessions)
  - Setup and tear down time not included in total operations time
- Initial stowage requirements
  - Three SPHERES satellites
  - Five Ultrasound (US) beacons
  - Laptop transmitter
  - Consumables (CO_2 tanks and battery packs)

Hardware Components

- SPHERES consists of three "satellites" eight-inches in diameter
  - Each satellite is self-contained with power (AA batteries), propulsion (CO_2 gas), computers, and navigation equipment
  - The satellites communicate with each other and an ISS laptop through a low-power wireless (RF) link
  - Operational volume is 6' x 6' x 6' (up to 10' x 10' x 10' is possible)
- Five ultrasound beacons located in the SPHERES work envelope act as a navigation system
  - Each beacon is self-contained and uses a single AA battery
  - A single beacon is approximately the size of a pager

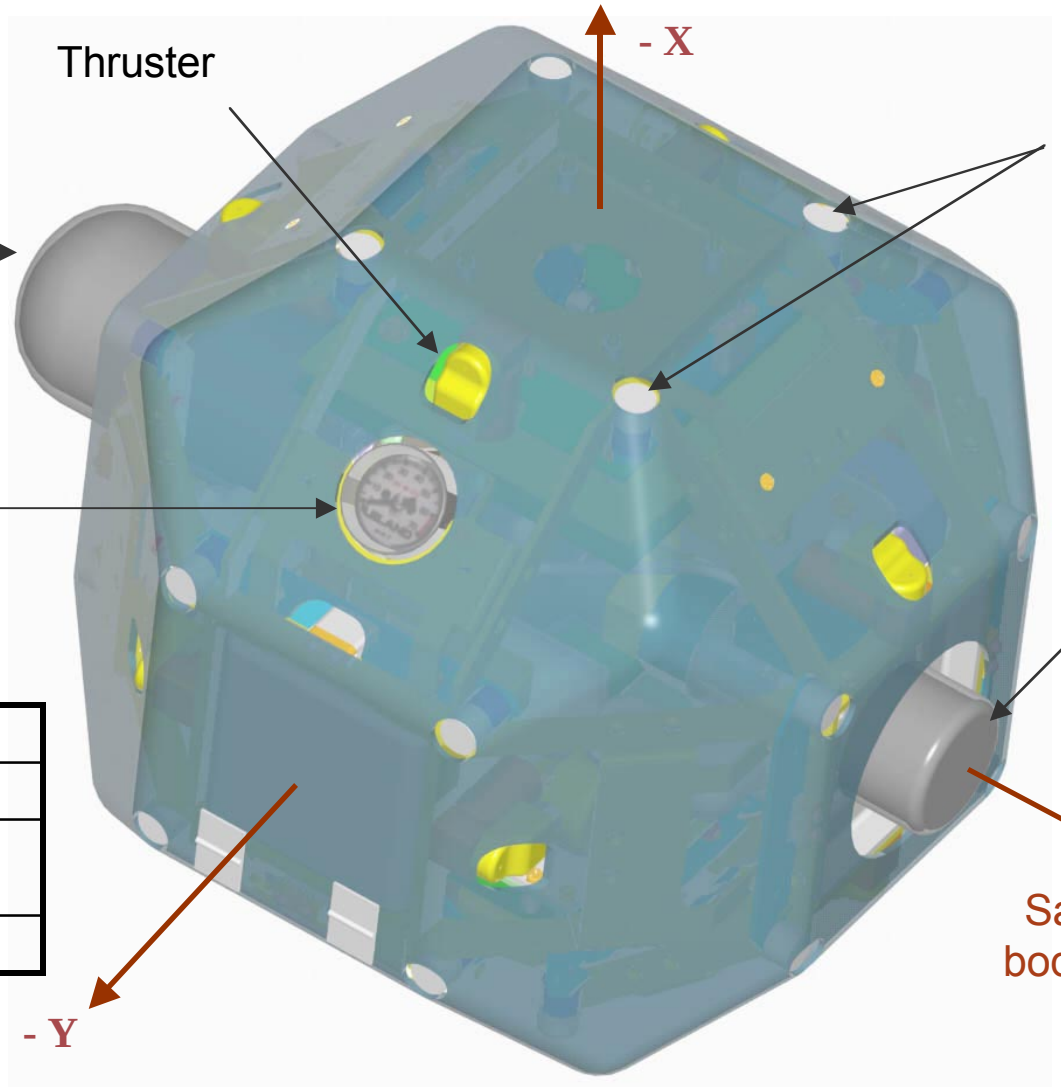


Satellite



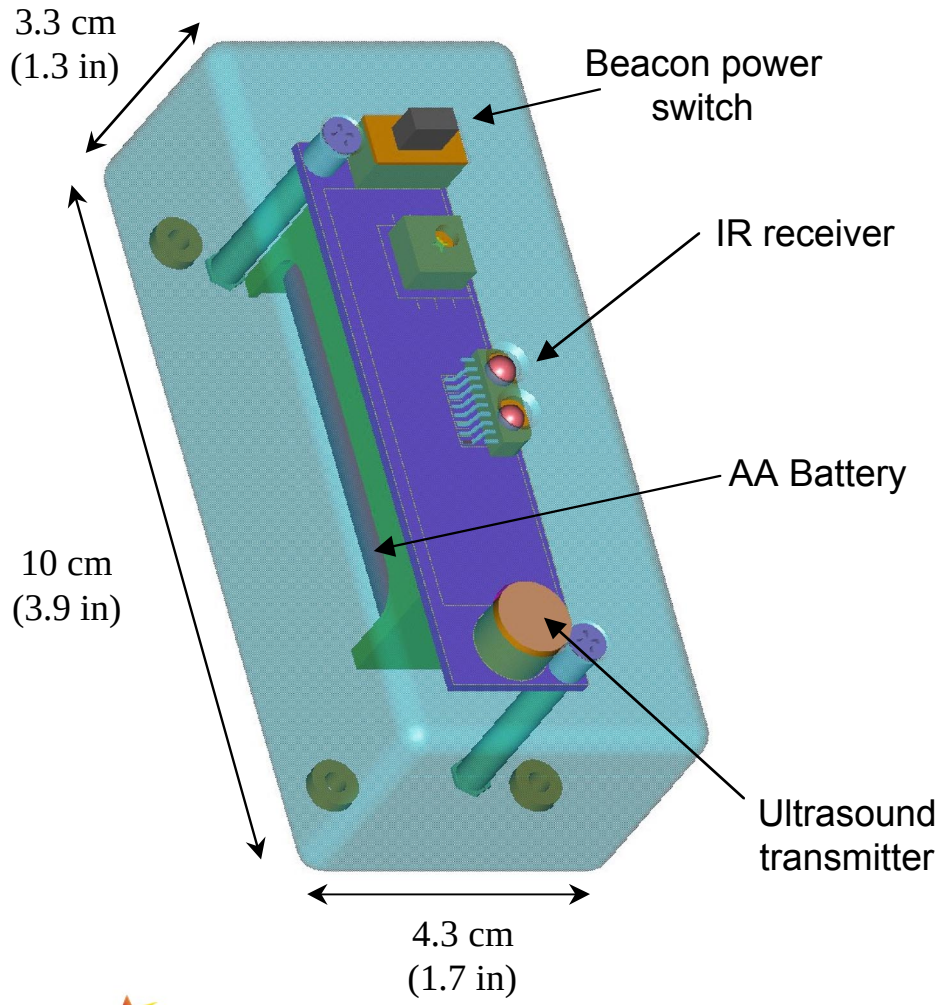
Ultrasound (US) beacon

SPHERES Satellite



Diameter	8 in (0.2 m)
Mass	7.85 lb (3.56 kg)
Thrust (single thruster)	<1 oz (0.2 N)
CO_2 Capacity	6 oz (170g)

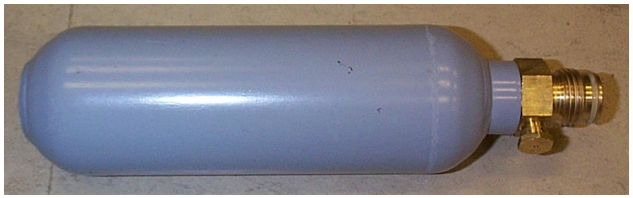
Ultrasound Beacon Structure

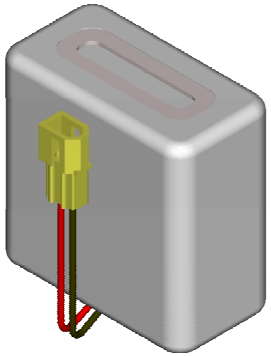


- Beacon components
  - One Infrared (IR) receiver
  - One US transmitter
  - One AA battery
  - Associated circuitry

Mass	0.25 lb (113 g)
Dimensions	1.3 x 3.9 x 1.7 in (3.3 x 10.0 x 4.3 cm)
Battery lifetime	>24hrs
US emitter frequency	40 kHz

Consumables



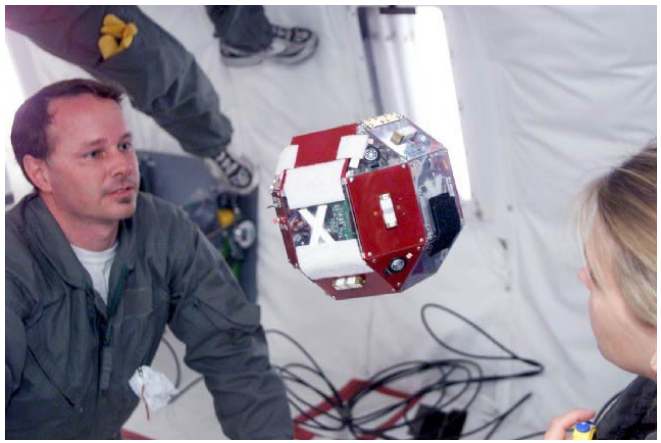


Replacement CO_2 tanks and battery packs

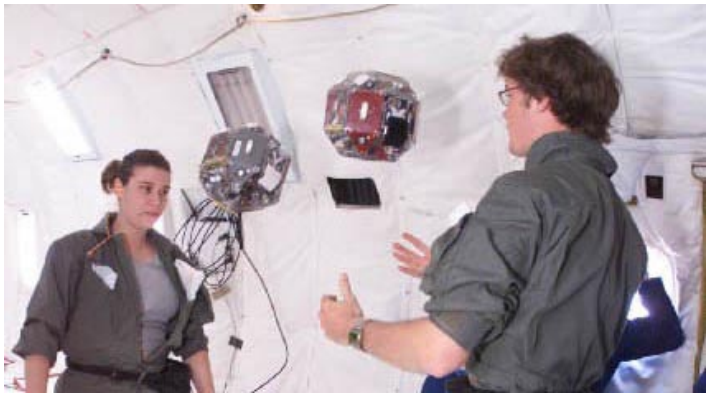
- CO_2 tanks
  - Contain liquid CO_2
  - Liquid is expanded to gas for expulsion
  - Mass: 517 g
  - Capacity: 170 g CO_2
  - Provides ΔV of 13.2 m/s
- Batteries
  - 16 AA x (1.5V) alkaline batteries housed in two battery packs
  - Satellites run for approximately 90 min on two battery packs

Operational Configurations

- Mode 1: Single satellite operations examples
  - Long term station-keeping
  - Minimum propellant maneuvers through pre-determined profiles
    - Isolated multidimensional rotation, multidimensional translation
    - Combined rotation & translation

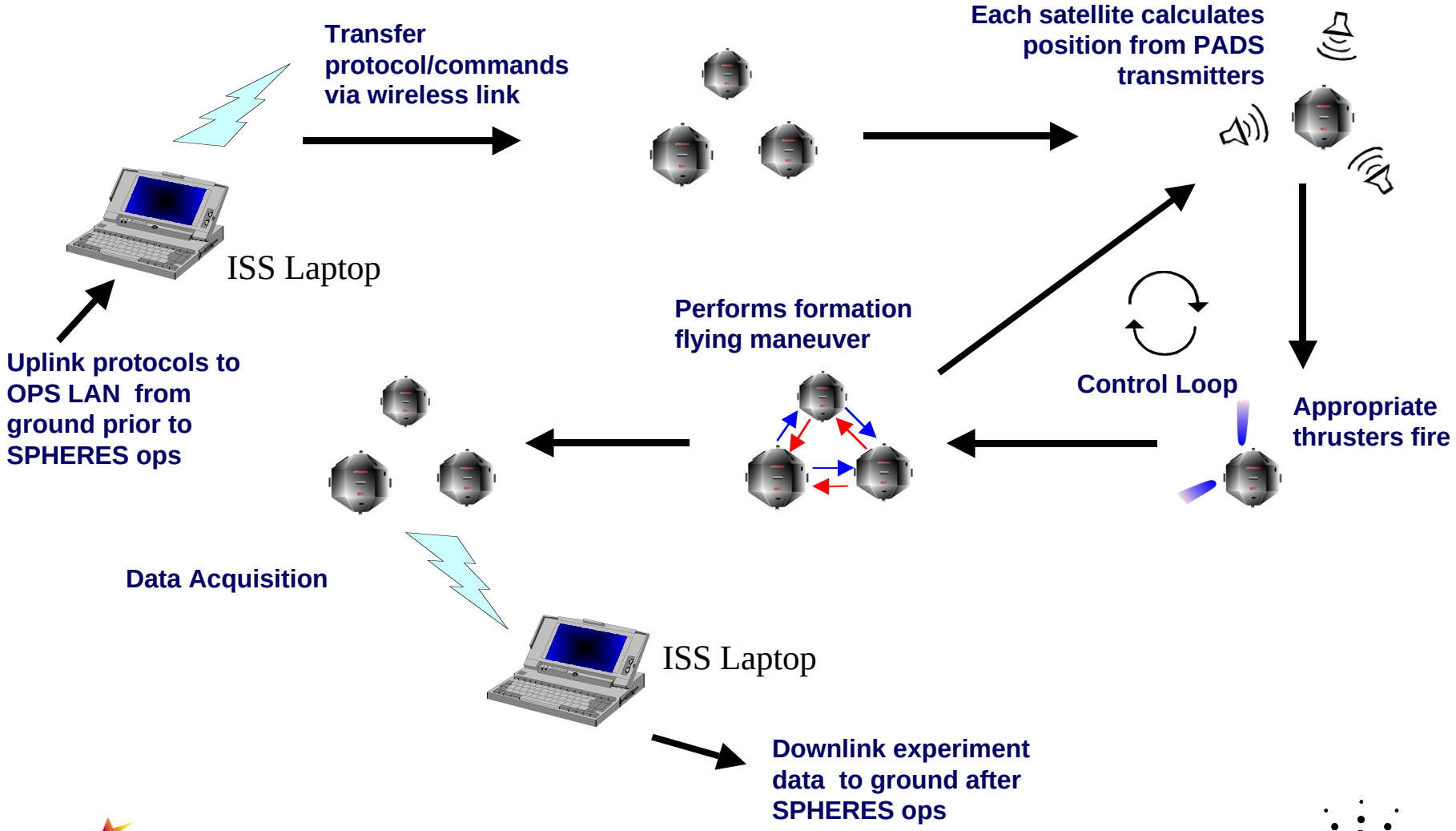


- Modes 2 and 3: Multiple satellite operations examples (two or three satellites)
  - Docking
  - Topological orientations
    - Independent control
    - Collision avoidance
    - Hierarchical control (leader-follower)
    - Distributed control (consensus)



Example configurations on the KC-135

SPHERES Typical Test Session Flow Chart



Prototype Testing on KC-135

Prototype Testing on KC-135

For More Information

Principal Investigator:

Prof. David Miller

Director, MIT Space Systems Laboratory

(617) 253-3288

millerd@mit.edu

Project Manager:

Steve Sell

Payload Systems Inc.

(617) 868-8086 x28

sell@payload.com